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PROJECT APOLLO

EVALUATION OF SAMPLED VELOCITY DISPLAY REQUIREMENT FOR THE TASK OF
NULLING HORIZONTAL VELOCITIES IN THE LEM SPACECRAFT LANDING MANEUVER

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SUMMARY

A four-degree-of-freedom analog partial simulation of the LEM lunar
landing maneuver has been conducted to determine the effect of sampling
rates and quantization level on the ability of the pilot to null the
horizontal velocities using the crosspointer velocity display. Results
of the study indicate that pilot evaluation (as measured on the Cooper
Rating Scale) is satisfactory for sampling rates of 3/sec and quantization
levels of 0.5 ft/sec. A preliminary analysis of the quantitative results
showed that for this sample rate and quantization level, the average touch-
down velocities were of the order of 0.3 ft/sec. Additional studies revealed
that using a first order filter having a time constant of 0.4 second improved
the pilot opinion of the control task. Supporting performance analyses
will be completed subsequently.

INTRODUCTION

During the landing approach and final vertical descent phases of the LEM powered descent, the horizontal velocity crosspointer display is driven by outputs computed in the LGC. Because of the overall LGC duty cycle, there are quantization and updating limitations during this portion of the powered descent. Concern has been expressed as to whether these limitations will affect the crew's ability to perform the landing maneuver. Specifically, the problem is most critical when the pilot attempts to null the forward and lateral velocity during the final vertical descent in the presence of the finite sampling rates and quantization levels available in the LGC.

To investigate this problem, the Guidance and Control Division conducted a small scale partial simulation of the final descent maneuver. The purpose of the simulation was to determine the effect of sampling rates and quantization level on the ability of the pilot to null the horizontal velocities. Recordings were made of the performance of the pilot in the nulling task and also his evaluation using the Cooper rating system of the sample frequency and quantization. This report gives the results of the quantitative evaluations by the pilots. Supporting performance analyses require a greater time to complete and will be reported subsequently.

DESCRIPTION OF SIMULATION

The simulator used to conduct this study consisted of a three-axis attitude indicator, a three-axis rotational controller, and a 5", two-beam low persistence oscilloscope representing the crosspointer velocity indicator (figure 1). The crosspointer velocity indicator had a scale range of ± 20 feet/second and a meter sensitivity of 0.065 in/ft/sec, which is identical to actual LEM velocity scale and sensitivity. Because the LEM velocity display has a 65 cps frequency response, no meter dynamics were included in the simulation.

The equations of motion were in four degrees of freedom, pilot pitch and yaw, and forward and lateral velocity. The attitude control system used employed simplified on-off thruster logic and had control powers and attitude deadbands equivalent to the actual LEM spacecraft. A block diagram of the equations of motion and attitude control system is shown in figure 2.

TEST PROCEDURE

The test maneuver used to determine the sampling rates and quantization levels consisted of having the pilots null the initial forward and lateral velocities. Time allowed for the test maneuver was 30 seconds, and the initial forward and lateral velocities were 10 and 5 feet/second, respectively.

Test Schedule

The test schedule consisted of having each of the four pilots make 30 runs in the order shown in the following table; the pilots were not informed as to the quantization and sampling rate for a particular run.

		QUANTIZATION LEVEL (ft/sec)				
		0.1	0.25	0.50	1.0	2.0
	1.0	4	10	22	16	19
	1.5	5	11	23	17	20
SAMPLING RATE (per sec)	2.0	6	12	1	18	21
	3.0	13	28	2	7	25
	4.0	14	29	3	8	26
	8.0	15	30	24	9	27

Evaluation of Test Results

Evaluation of test results was by means of pilot opinion using the Cooper Rating Scale (Table 1). In addition, the pilots were also requested to state whether they could make a landing using that particular sampling rate and quantization level. Recordings were made of the following variables:

1. True forward and lateral velocity
2. Quantized forward and lateral velocity
3. Quantized and sampled forward and lateral velocity
4. Integrated square error of true forward and lateral velocity as measured about zero (null)

DISCUSSION OF TEST RESULTS

The test results are presented in the form of graphs showing boundaries of satisfactory, acceptable, and unacceptable performance as functions of sample rate and quantization level. The graphs were constructed by interpolating between the average of the pilot Cooper Ratings for the test points examined. In addition, the response of the pilots as to whether the particular system under investigation could be used to land is also plotted as a function of sample rate and quantization level. The boundaries contain areas of yes, doubtful, and no responses.

Results of Pilot Opinion

The pilot opinion results show that the satisfactory boundary for velocity control was for sampling rates greater than 2/sec and quantizing levels less than 0.6 ft/sec. As indicated in figure 3, the boundary for the satisfactory region is quite insensitive to sampling above 2/sec although satisfactory control can be achieved with sample rates as low as 1/sec for small quantizing levels. The acceptable region for control exists out to quantizing levels of the order of 1.5/sec and is also insensitive to sampling rate above rates of 1/sec. These results are consistent with the low response requirements of the control task.

As noted in the test schedule, the pilots were not told what quantizing level and sampling rates were being evaluated. Observation of their control and subsequent comments generally indicated the pilots could not tell the difference between low sample rates and small quantizing and high sample rates and large quantizing levels. In fact, once a given quantizing had been established, the sample rate could (within reason) be changed at will without having the pilot alter the rating appreciably. Also, a review of the ratings of the various combinations showed that the tendency existed to rate quantization levels of 0.1 ft/sec worse than levels of 0.25/sec. Above 2 samples/sec, the ratings of quantizing levels of 0.1 and 0.5 were very nearly the same. This leads to the conclusion that the pilots objected to small discrete pulses about as much as a larger discrete jump. However, it appeared the pilots tended to exercise a little better control at the 0.5 quantizing levels than at the 0.1 level once a null had been established because the velocity display did not necessarily jump each time a new sample period occurred. An optimum for quantizing level based on pilot opinion appears to be centered about 0.25/sec, but the control performance does not indicate any such optimum. Controllability between 0.1 and 0.5 ft/sec quantizing levels and reasonable sample rates was essentially flat with respect to the measure of integral square error as indicated in the following table:

	QUANTIZATION LEVEL (ft/sec)		
	0.1	0.25	0.5
INTEGRAL SQUARE ERROR	37	41	41

In addition, a preliminary analysis of the quantitative results indicates the average touchdown velocities for these particular quantization levels is of the order of 0.3 ft/sec.

Effect of Quantizing Level on Landing Control

The pilot responses as to whether the spacecraft could be landed using the particular combination of sampling rates and quantizing levels are shown in figure 4. As the figure shows, the YES area corresponds roughly to the satisfactory region of figure 3, but the DOUBTFUL region is somewhat less than the acceptable region for figure 3. From this, it appears that quantizing levels of less than 1 ft/sec are necessary for adequate landing control. Also, note that the responses, for the most part, are also relatively insensitive to sampling rates greater than 2/second.

Effect of Filtering on Cooper Rating

Because the pilots tended to dislike the discrete jumps occurring in the velocity display, a first order filter was inserted between the velocity display and simulated LGC output to determine its effect on Cooper Rating. Except for one filtering frequency, no data were recorded, but the results for the one filter frequency indicated that pilot opinion changed remarkably. For the unrecorded data, observations showed that for small quantizing levels, the tendency was to rate the system somewhat better with 0.1 sec time constant and degrade them as the filter time constant was increased to 1 second because of the phase shift or time lag in velocity meter response. For quantizing levels of 1 and 2 ft/sec, the satisfactory boundary began to move outward as the time constant was increased to 1 second although no amount of filtering made the 2 ft/sec level better than acceptable. In fact, the pilot testing the filtered display indicated the landing could be made without difficulty with sample rates greater than 2/second at 1 ft/sec quantization (the previous response without filtering was no). At least two major items contribute to this: (1) the display did not make discrete jumps and (2) trend information was available almost continuously. The final time constant selected for investigation was 0.4 second which appeared to be a good compromise between display smoothing and display lag. The results of the pilot evaluation reveal the satisfactory region approached 1 ft/sec and the acceptable boundary went out to 2 ft/sec. This is shown in figure 5 which also includes the boundaries of figure 3 for comparison. A comparison of the time history of the difference in response of the filtered and unfiltered siaplay inputs for 0.5 ft/sec quantization and a sample rate of 3/sec is shown in figure 6. These time histories show that the filtered velocity display input is almost of analog content whereas the unfiltered display information has discrete jumps of 0.5 ft/sec. The filtered display, of course, lags the true velocity by 0.4 second, but this is apparently not detrimental to control because of the long spacecraft response times. Also, because the lateral acceleration used under these conditions does not normally exceed 1 ft/sec^2, the dynamic error in velocity caused by the display filter at any instant is less than .4 ft/sec. The opening up of the satisfactory boundary leads to the conclusion that the LEM crosspointer velocity display would be more acceptable to the pilot if a first order filter were inserted between it and the LGC output.

CONCLUDING REMARKS

The results of this study indicate that in the opinion of the pilot an LGC quantization of 0.5 ft/sec and sampling rate of the order of 3/sec will provide velocity display information sufficiently accurate for the pilot to null the forward and lateral velocities of the LEM. The studies also indicate that a filter having a time constant of 0.4 second will allow the pilot to better control nulling of the horizontal velocity vector at touchdown. These results, however, are conditioned by the fact that only four degrees of spacecraft freedom were used in this simulation study and the study results should be verified in a more elaborate simulation of the LEM lunar landing maneuver.

TABLE I - PILOT OPINION RATING SYSTEM FOR UNIVERSAL USE

ADJECTIVE RATING	NUMERICAL RATING	DESCRIPTION	PRIMARY MISSION ACCOMPLISHED?	CAN BE LANDED
SATISFACTORY	1	EXCELLENT, INCLUDES OPTIMUM	YES	YES
	2	GOOD, PLEASANT TO FLY	YES	YES
	3	SATISFACTORY, BUT WITH SOME MILDLY UNPLEASANT CHARACTERISTICS	YES	YES
UNSATISFACTORY	4	ACCEPTABLE, BUT WITH UNPLEASANT CHARACTERISTICS	YES	YES
	5	UNACCEPTABLE FOR NORMAL OPERATION	DOUBTFUL	YES
	6	ACCEPTABLE FOR EMERGENCY CONDITION ONLY*	DOUBTFUL	YES
UNACCEPTABLE	7	UNACCEPTABLE EVEN FOR EMERGENCY CONDITION*	NO	DOUBTFUL
	8	UNACCEPTABLE - DANGEROUS	NO	NO
	9	UNACCEPTABLE - UNCONTROLLABLE	NO	NO
CATASTROPHIC	10	MOTIONS POSSIBLY VIOLENT ENOUGH TO PREVENT PILOT ESCAPE		

* (FAILURE OF A STABILITY AUGMENTER)

Operation categories (left column):
- NORMAL OPERATION
- EMERGENCY OPERATION
- NO OPERATION

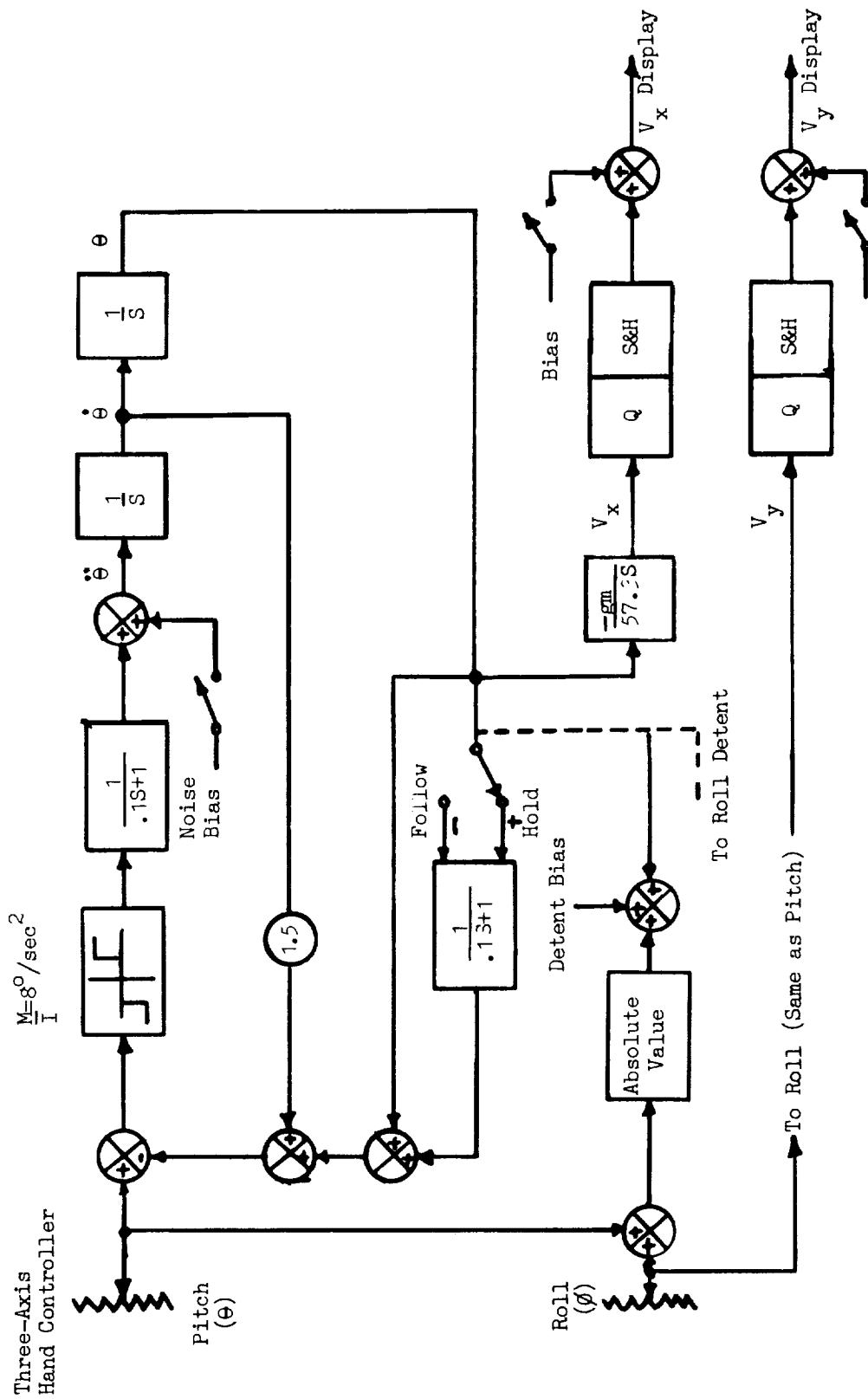PG 51733
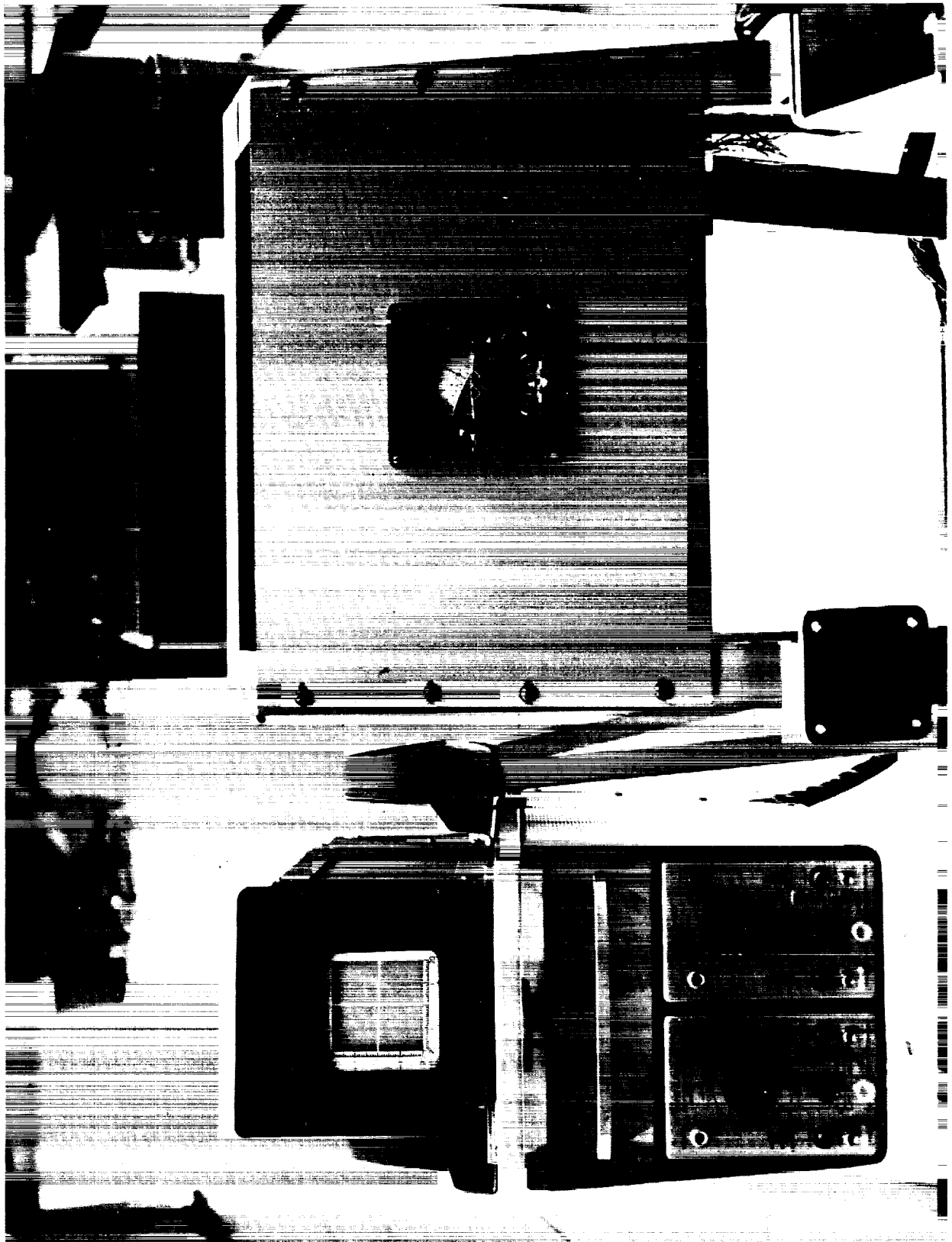
FIGURE 1 - TEST COCKPIT
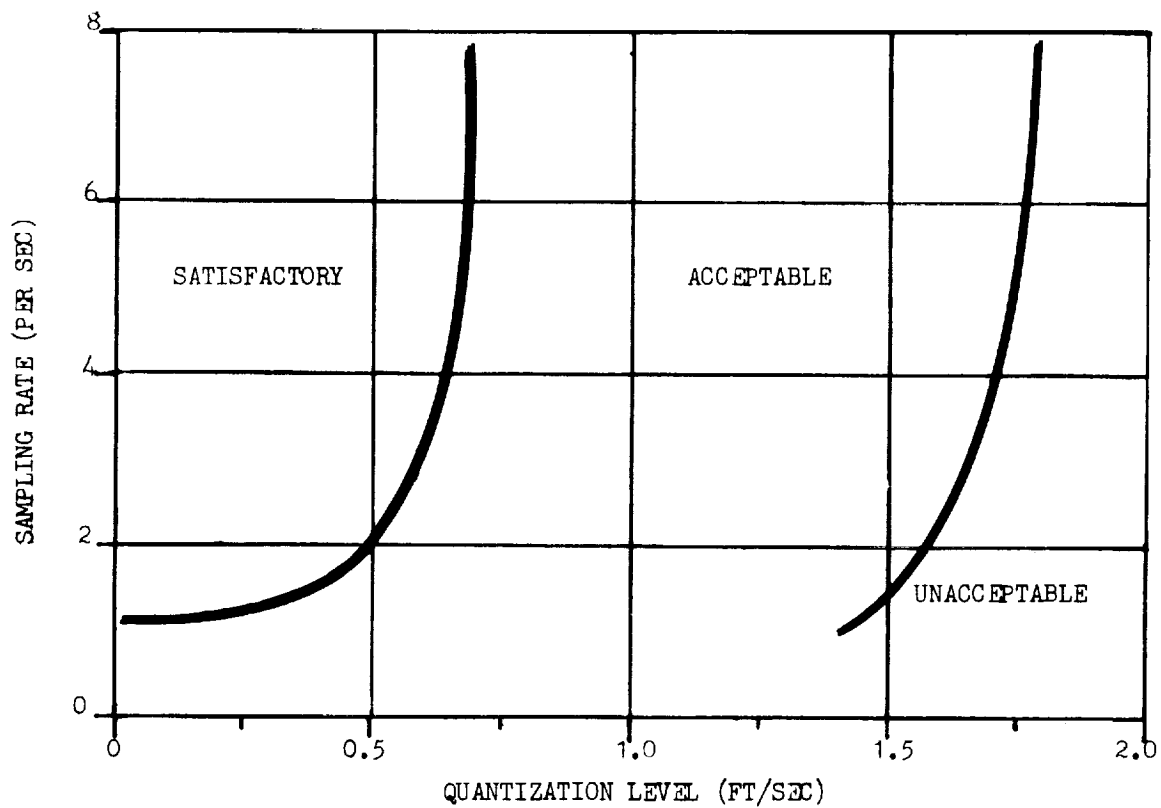
FIGURE 2 - SYSTEM DIAGRAM

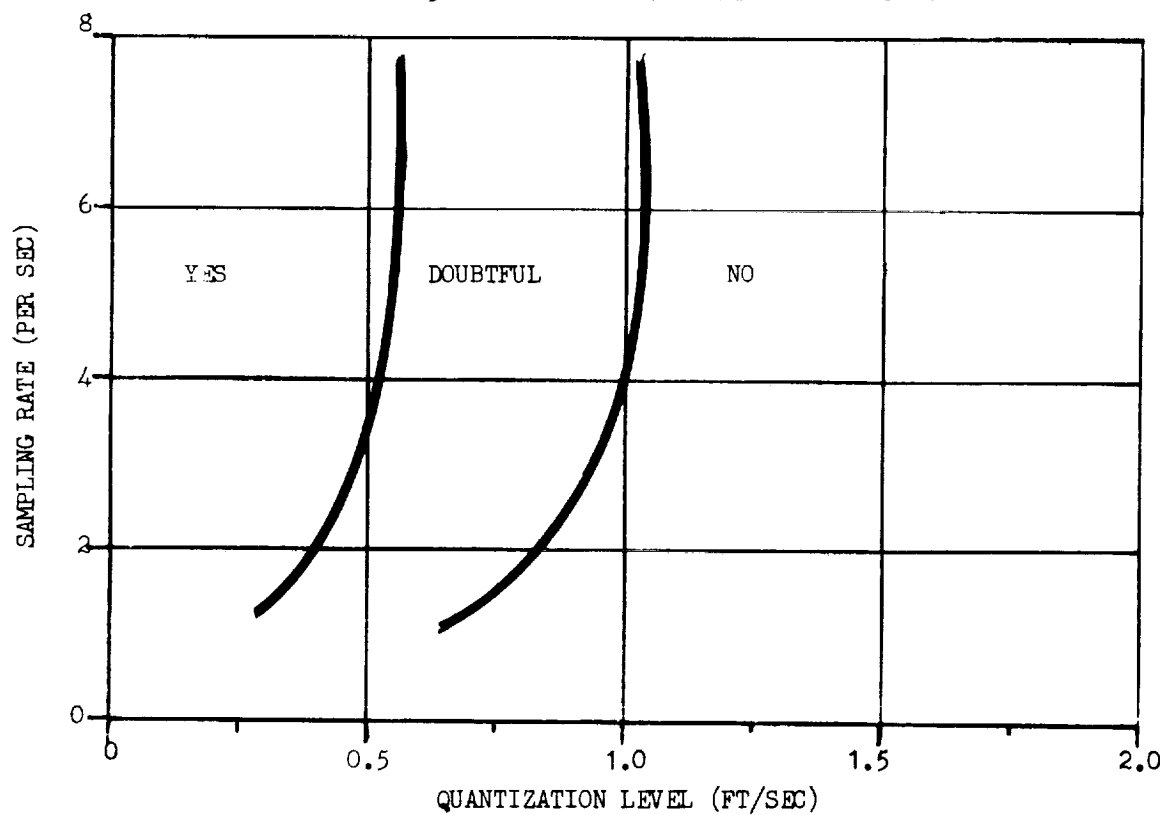FIGURE 3 - PILOT RATING OF VELOCITY DISPLAY

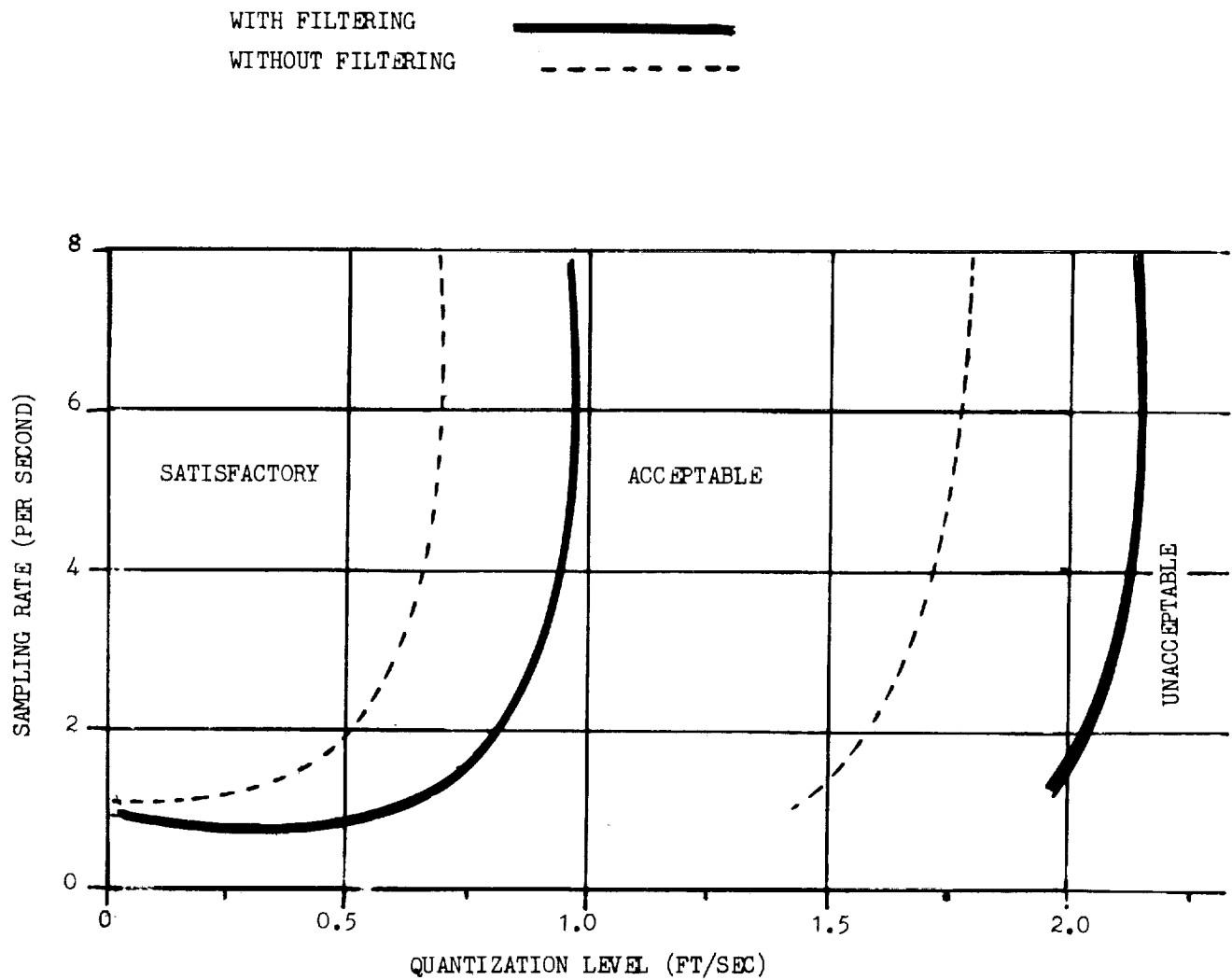FIGURE 4 - PILOT EVALUATION OF ABILITY TO LAND WITH VELOCITY DISPLAY

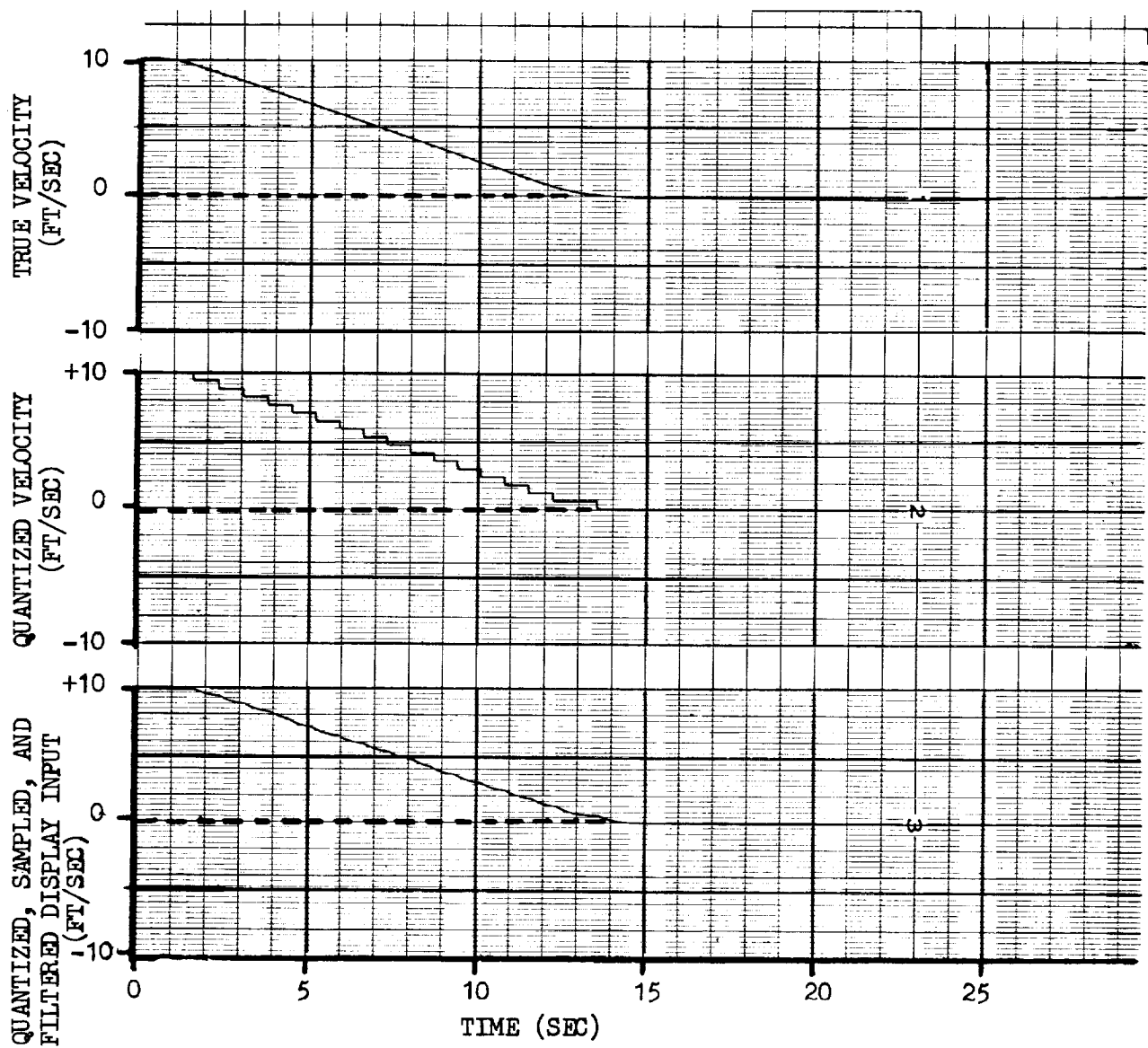FIGURE 5 — EFFECT OF 0.4 SECOND TIME CONSTANT FILTER ON
PILOT RATING

FIGURE 6 - EFFECT OF 0.4 SECOND TIME CONSTANT FILTER ON VELOCITY DISLAY INPUT
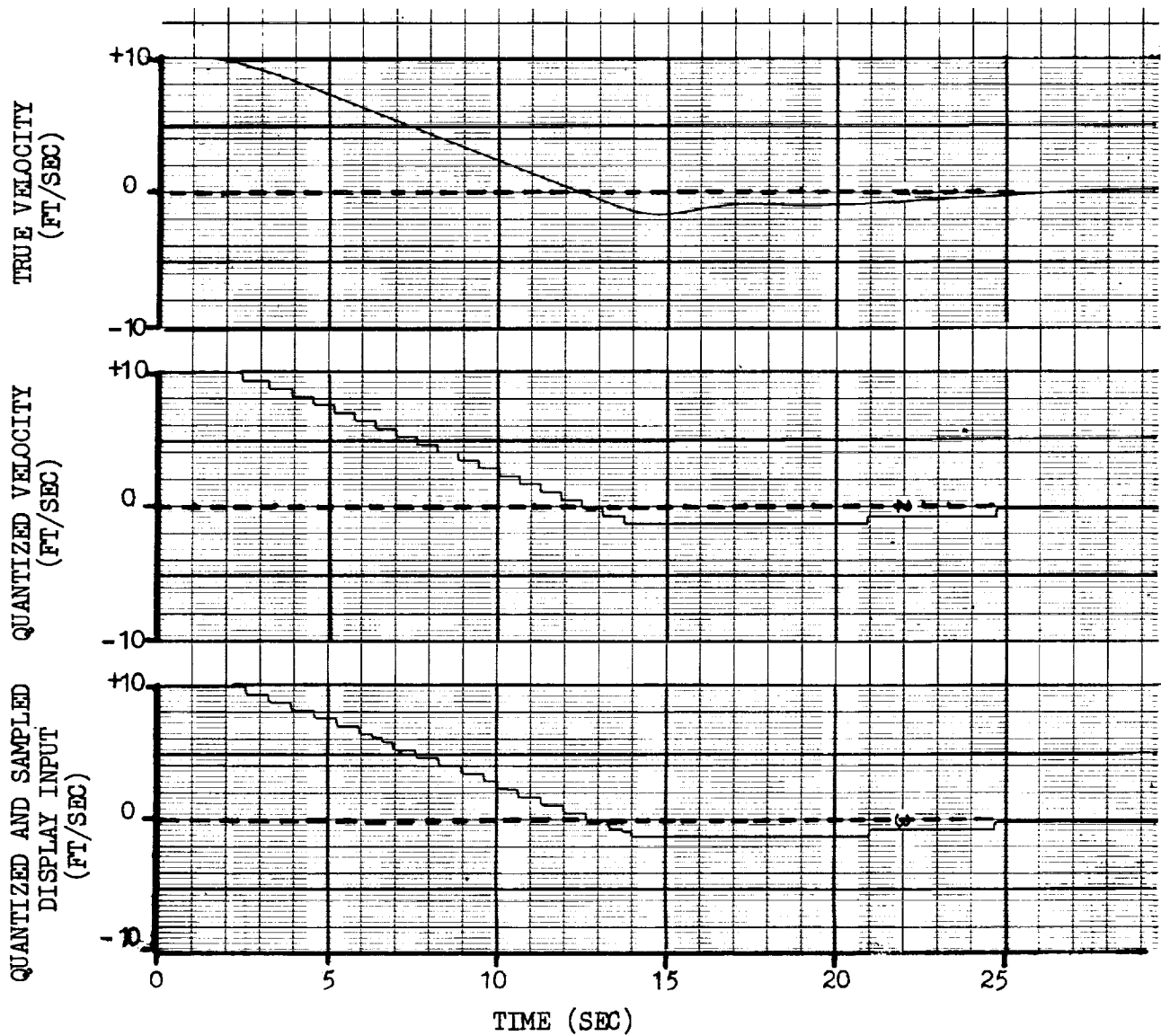(0.5 FT/SEC QUANTIZATION LEVEL, 3 SAMPLES/SEC)

a. WITH FILTERING

FIGURE 6 – (Continued)

b. WITHOUT FILTERING